(12) UK Patent Application (19) GB (11) 2 384 752 (13) A

(43) Date of A Publication 06.08.2003

(21) Application No 0301948.6

(22) Date of Filing 28.01.2003

(30) Priority Data
(31) 10061828 (32) 31.01.2002 (33) US

(71) Applicant(s)
Hewlett-Packard Company
(Incorporated in USA - Delaware)
3000 Hanover Street, Palo Alto,
California 94304, United States of America

(72) Inventor(s)
Rio T Rivas
Shen Buswell
Mehrgan Khavari
Jeffrey R Pollard

(74) Agent and/or Address for Service
Carpmaels & Ransford
43 Bloomsbury Square, LONDON,
WC1A 2RA, United Kingdom

(51) INT CL^7
B41J 2/16

(52) UK CL (Edition V)
B6F FLP
B3V VLB

(56) Documents Cited
EP 0764533 A2 **EP 0609012 A2**
US 5455998 A

(58) Field of Search
UK CL (Edition V) **B6F**
INT CL^7 **B41J**
Other: **Online: EPODOC JAPIO WPI**

(54) Abstract Title
Slotted substrates and methods and systems for forming same

(57) Methods and systems for forming slots (604) in a substrate (606) that has opposing first and second surfaces. The method makes a laser cut through either the first surface (610) or second surface (612) of the substrate (606) sufficient to form a first trench (802). Material is also removed through the other of the first and second surfaces effective to form, in combination with the laser cut, a slot (604). At least a portion of the slot (604) passes entirely though the substrate (606), and the slot (604) has an aspect ratio greater than or equal to 1. Furthermore, the maximum width of the slot (604) can be about 50 percent or less of the thickness of the substrate (606). The substrate (606) may be a semiconductor substrate. The method may be used in the manufacture of fluid ejecting devices such as a printhead.

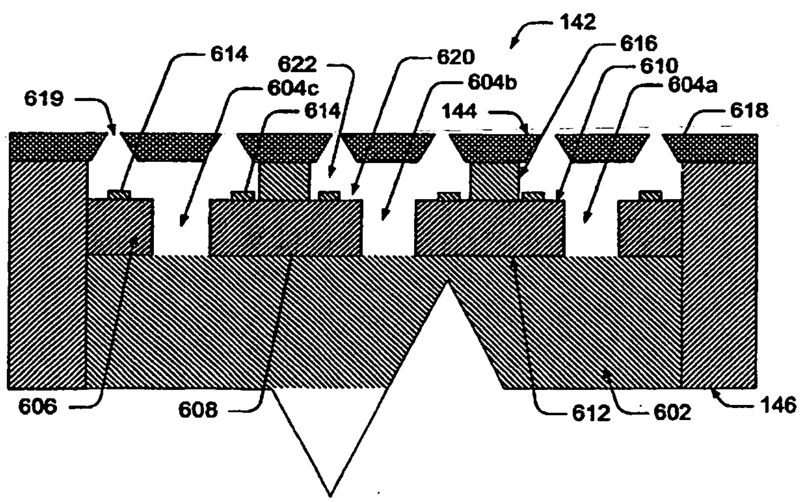


Fig. 6

BEST AVAILABLE COPY

GB 2 384 752 A

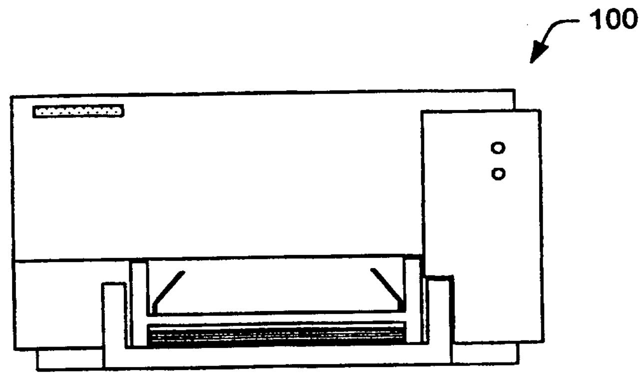

100

Fig.1

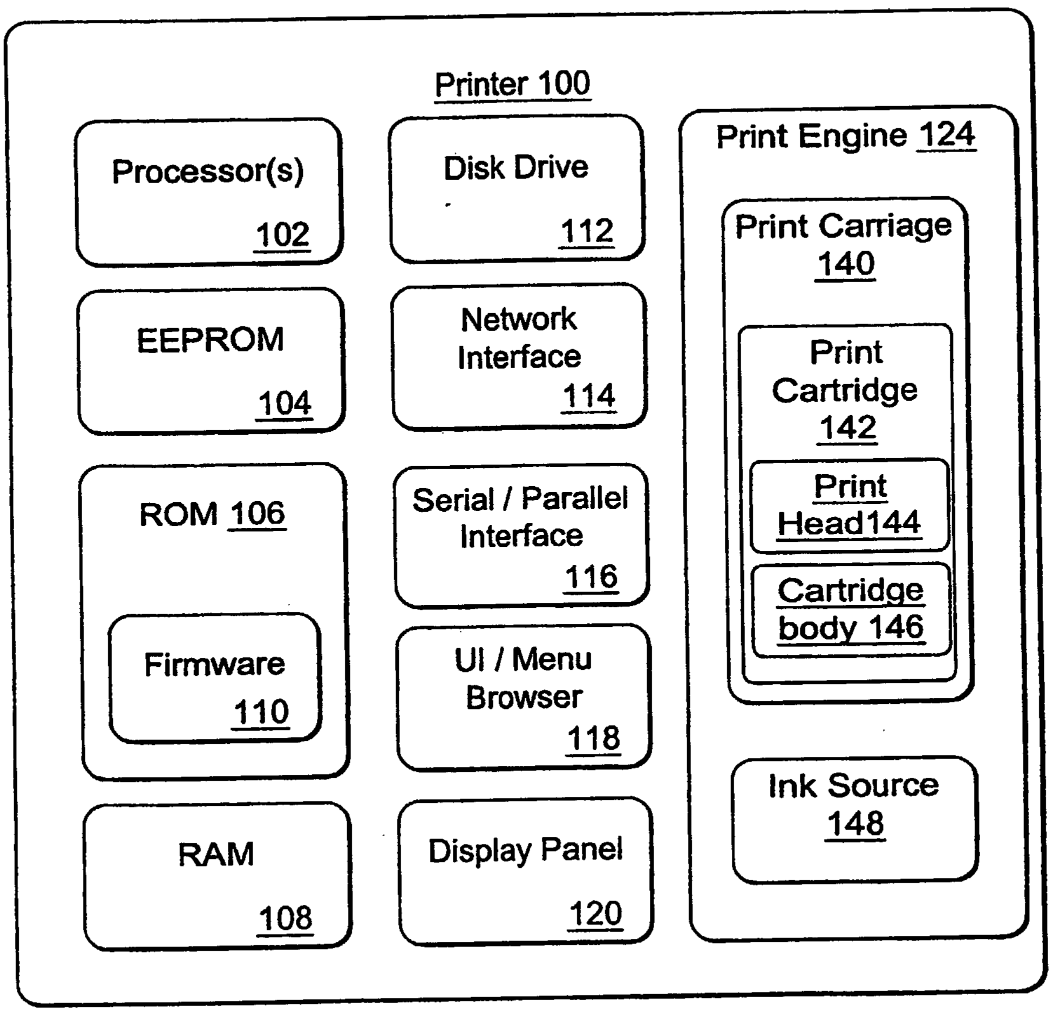

Printer 100
Processor(s) 102
EEPROM 104
ROM 106
Firmware 110
RAM 108
Disk Drive 112
Network Interface 114
Serial / Parallel Interface 116
UI / Menu Browser 118
Display Panel 120
Print Engine 124
Print Carriage 140
Print Cartridge 142
Print Head144
Cartridge body 146
Ink Source 148

Fig. 2

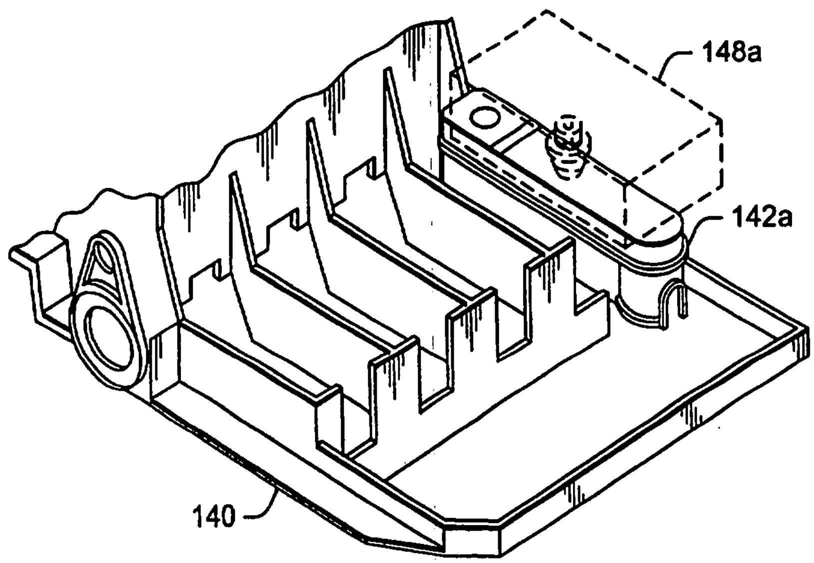


FIG. 3

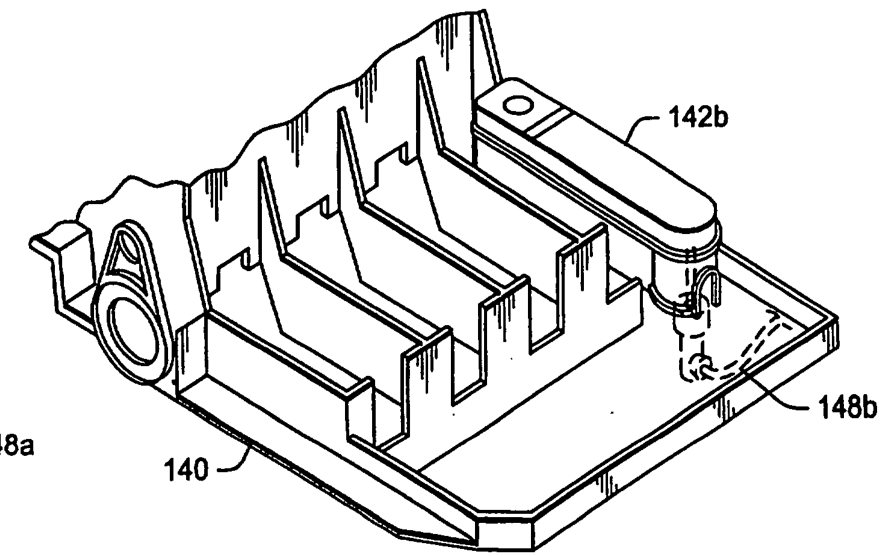


FIG. 4

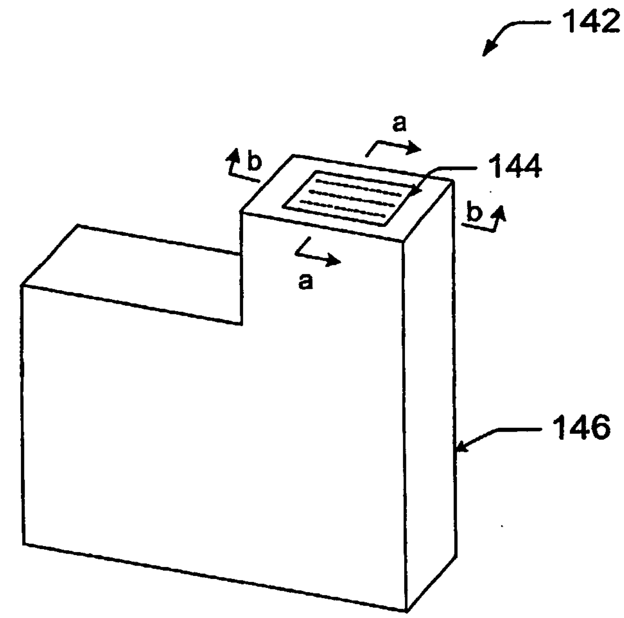

142
a
b
144
b
a
146

Fig. 5

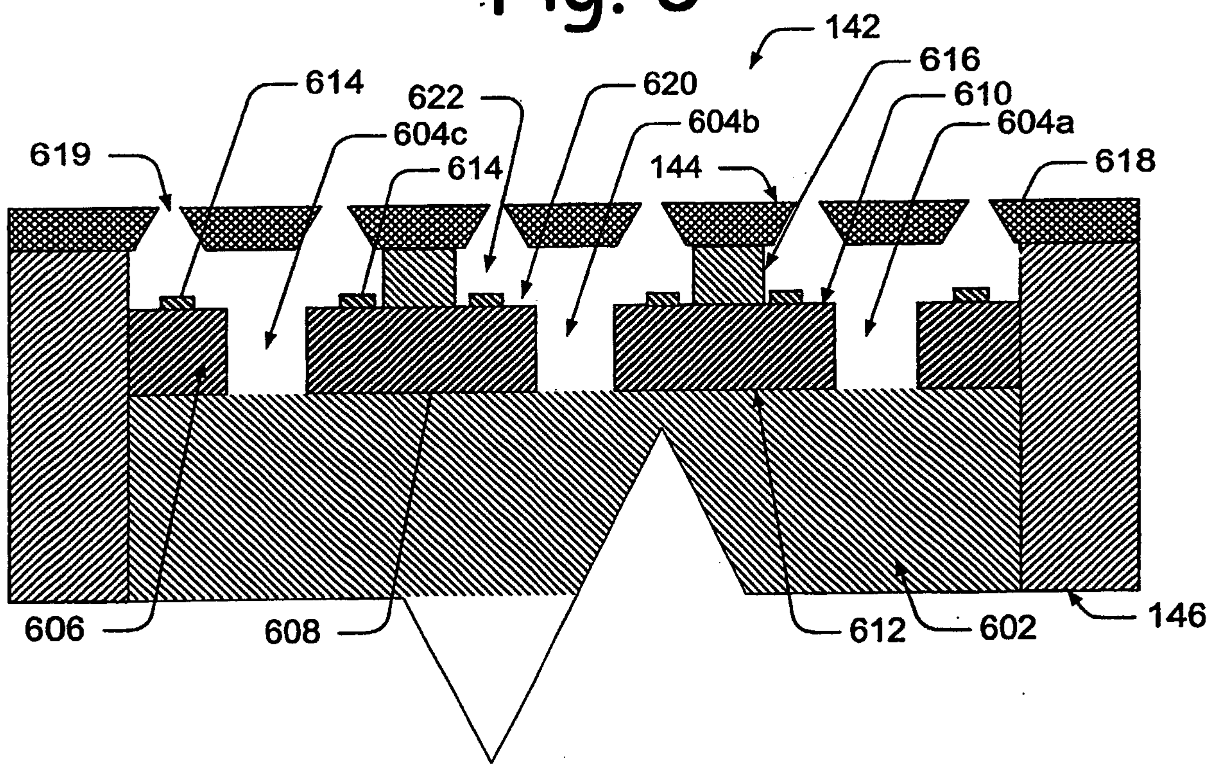

142
614
622
620
616
610
604c
604b
604a
619
614
144
618
606
608
612
602
146

Fig. 6

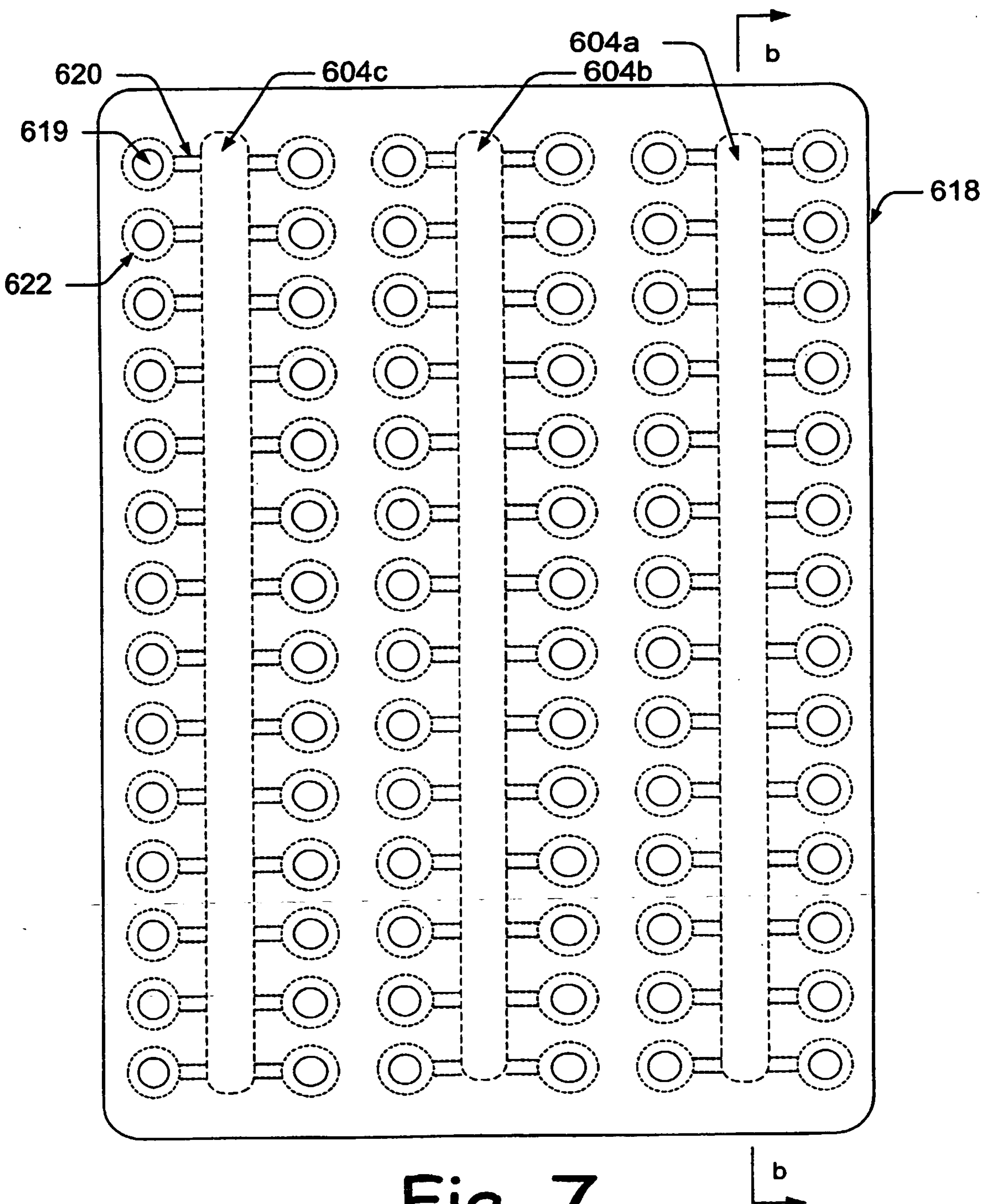


Fig. 7

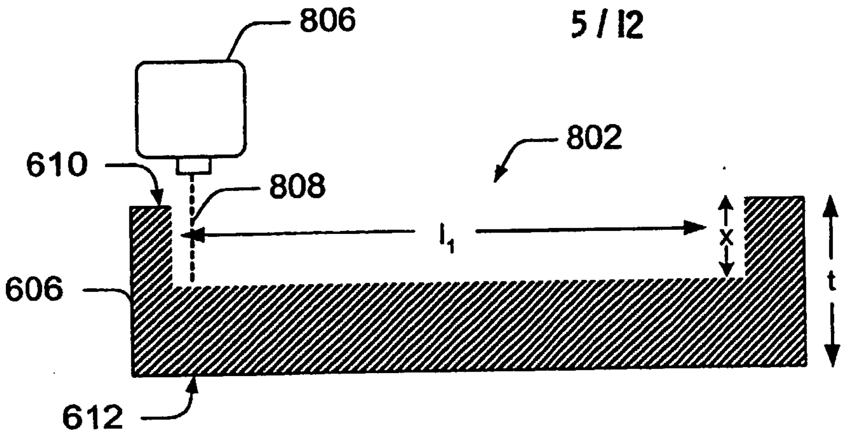


Fig. 8a

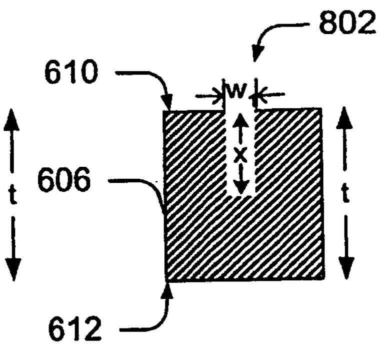


Fig. 8b

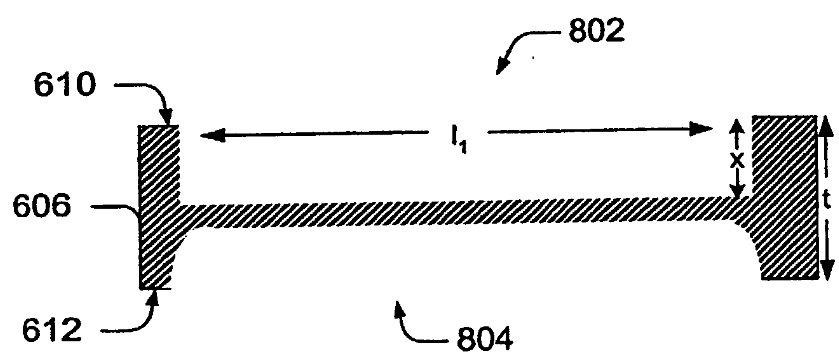


Fig. 8c

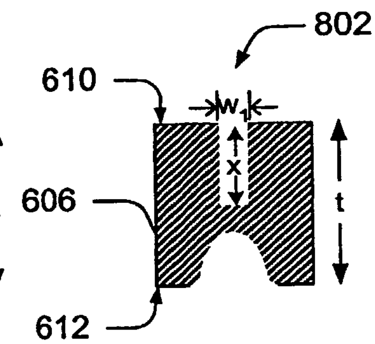


Fig. 8d

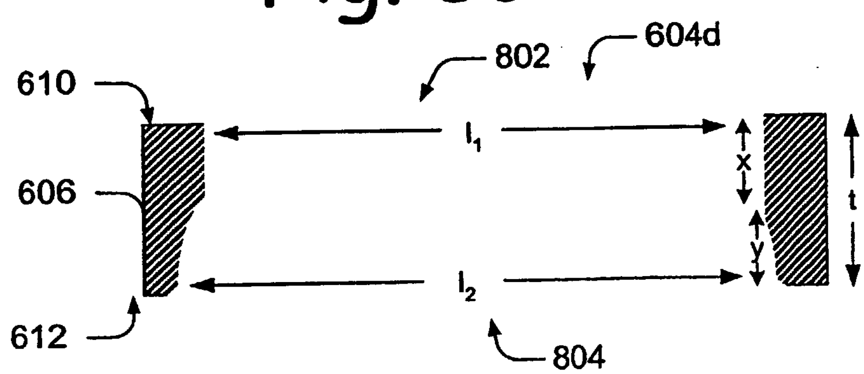


Fig. 8e

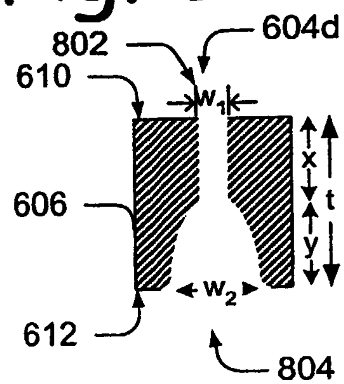


Fig. 8f

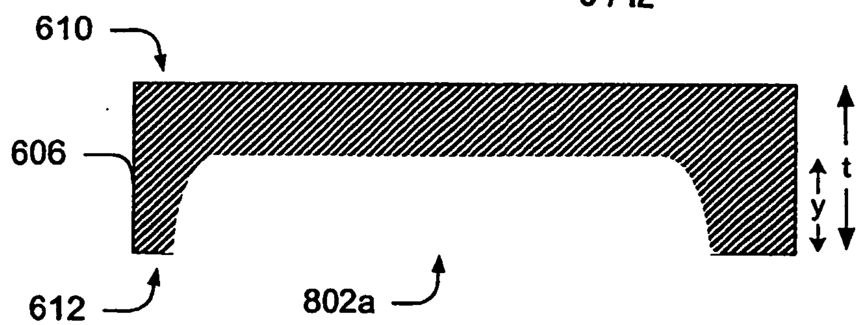


Fig. 9a

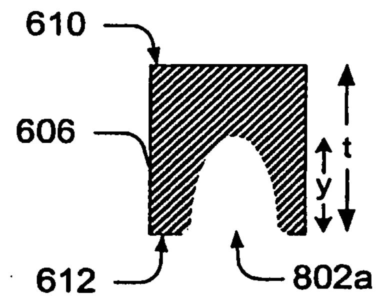


Fig. 9b

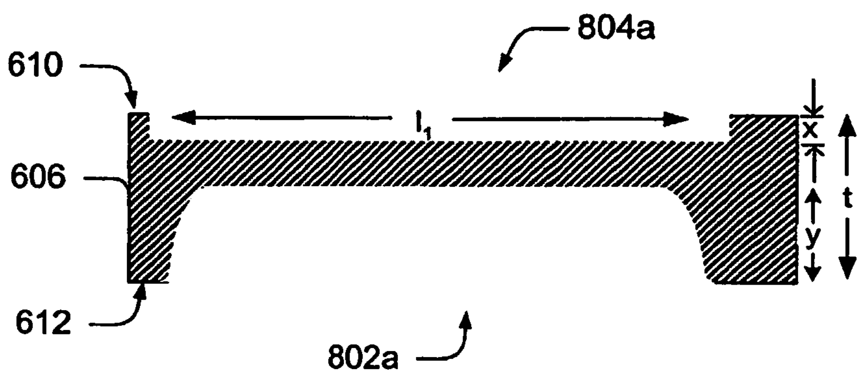


Fig. 9c

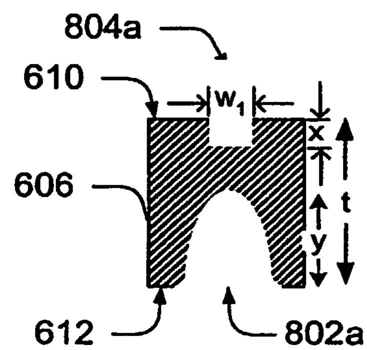


Fig. 9d

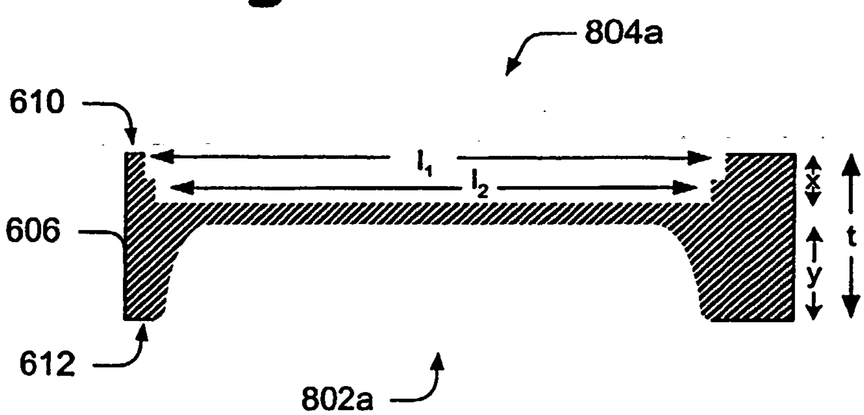


Fig. 9e

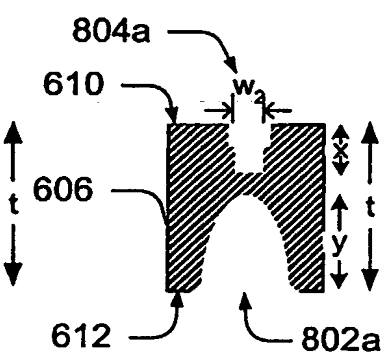


Fig. 9f

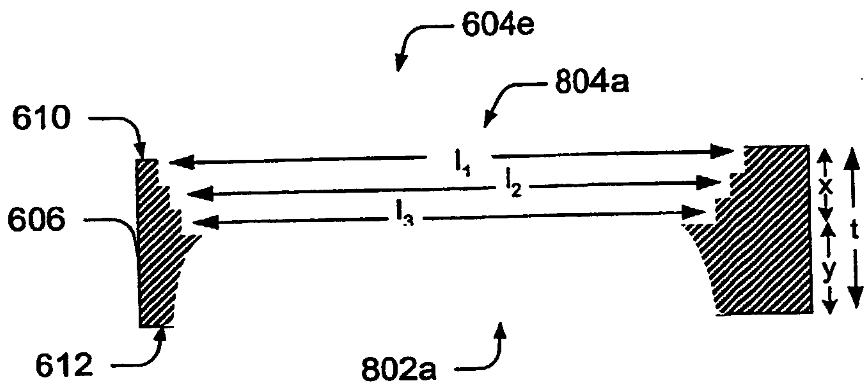

604e
804a
610
606
612
802a
l_1
l_2
l_3
x
y
t

Fig. 9g

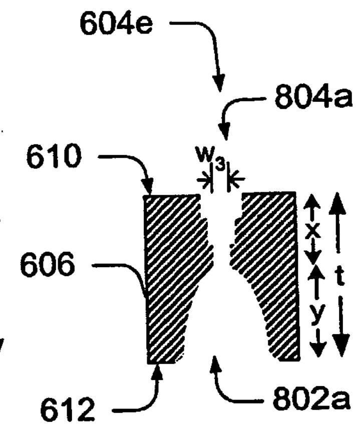

604e
804a
610
606
612
802a
w_3
x
y
t

Fig. 9h

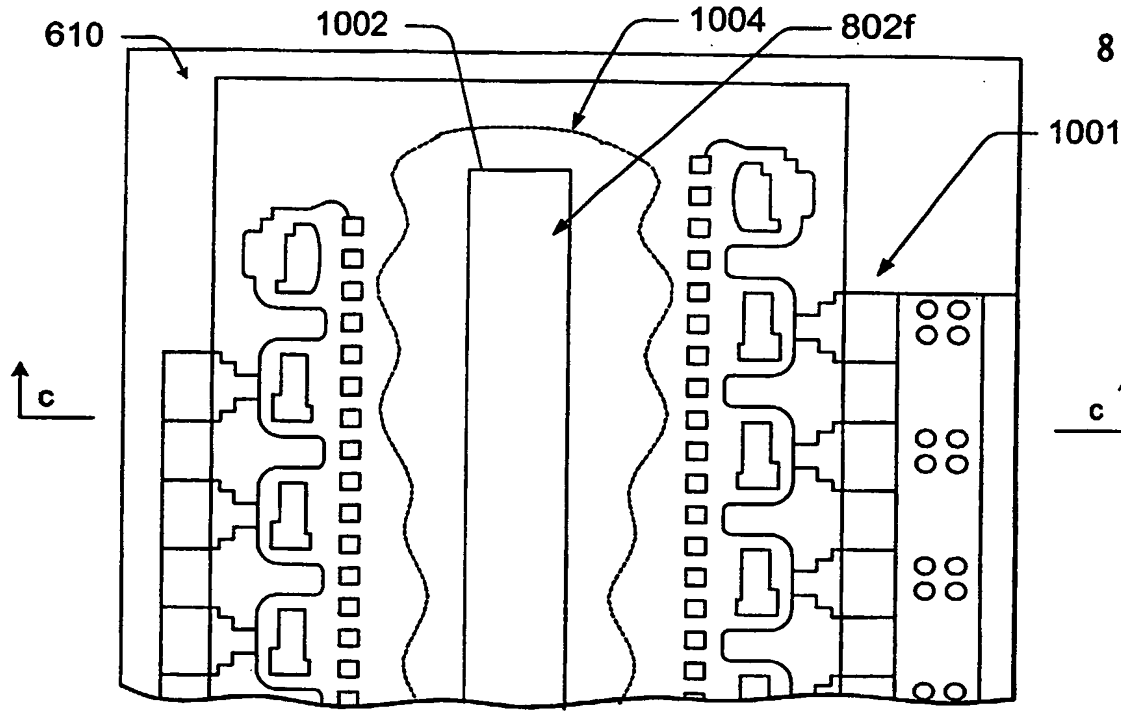


Fig. 10a

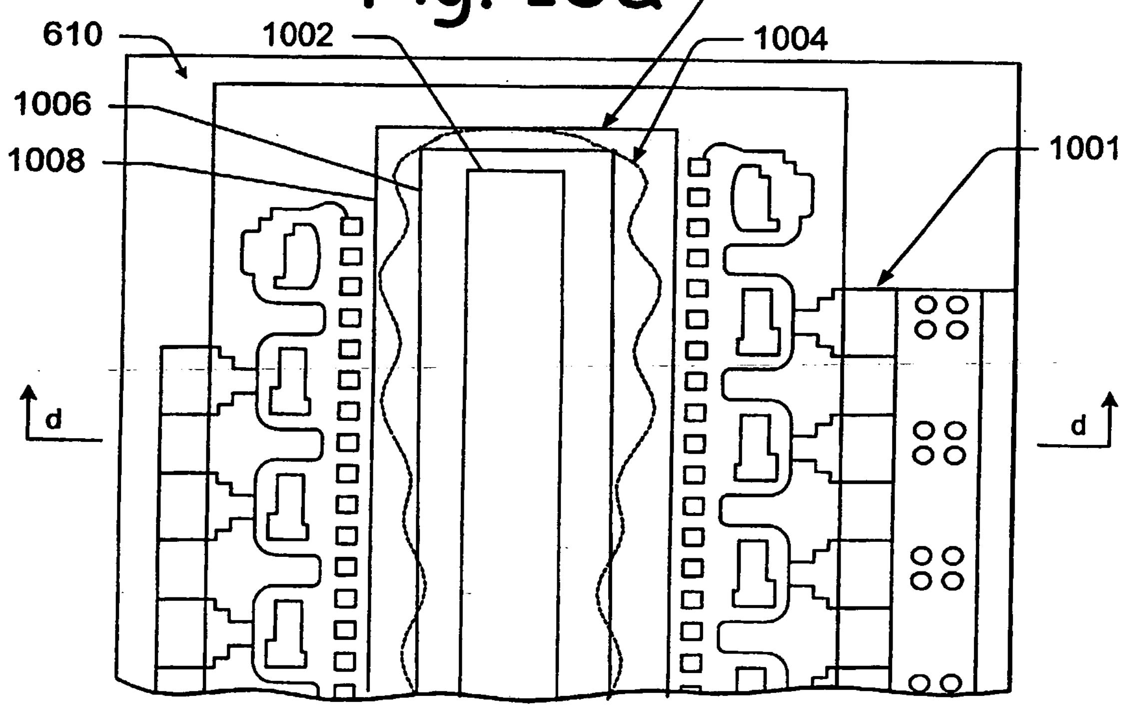


Fig. 10e

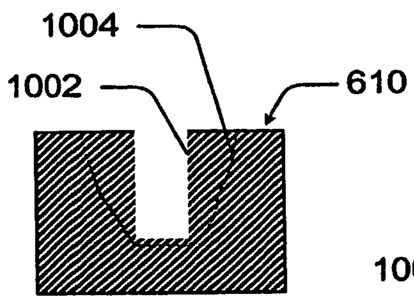


Fig. 10b

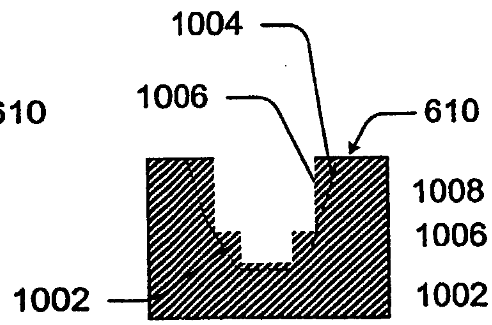


Fig. 10c

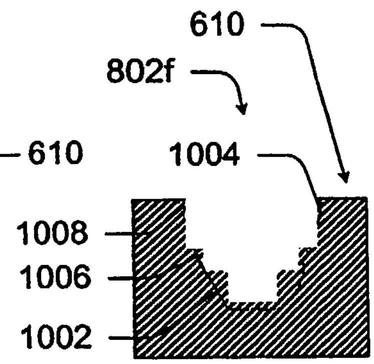


Fig. 10d

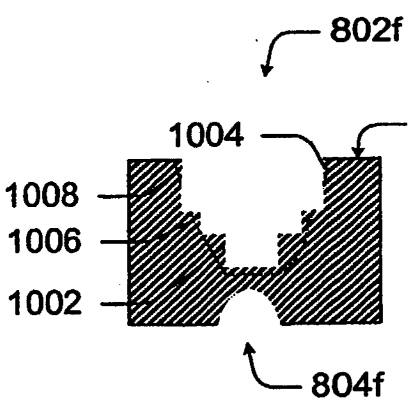


Fig. 10f

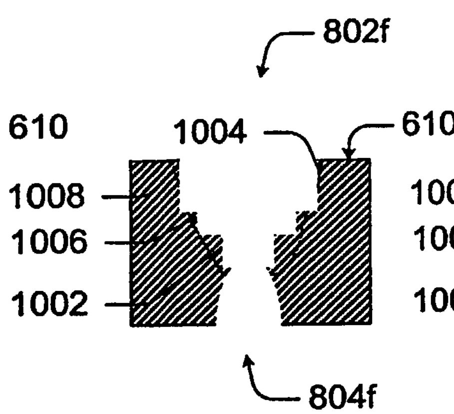


Fig. 10g

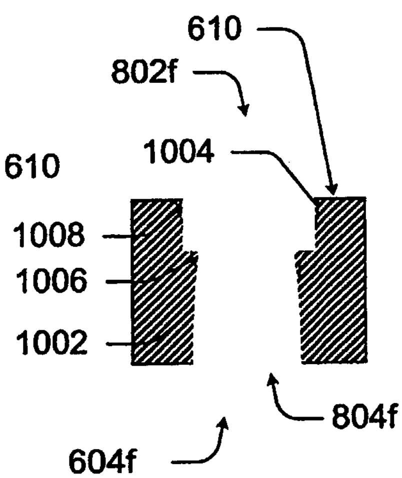


Fig. 10h

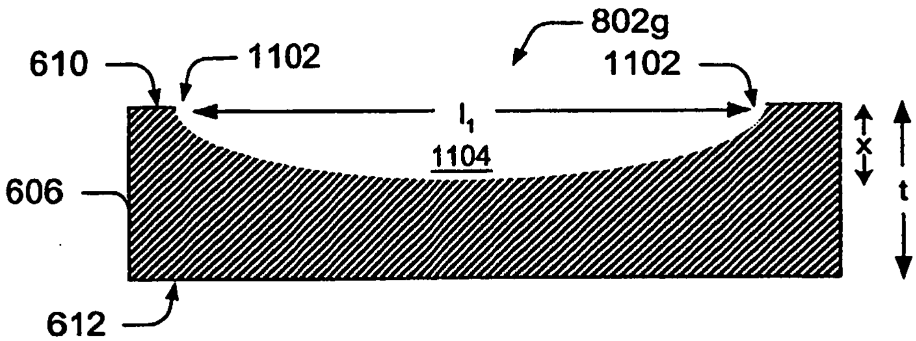


Fig. 11a

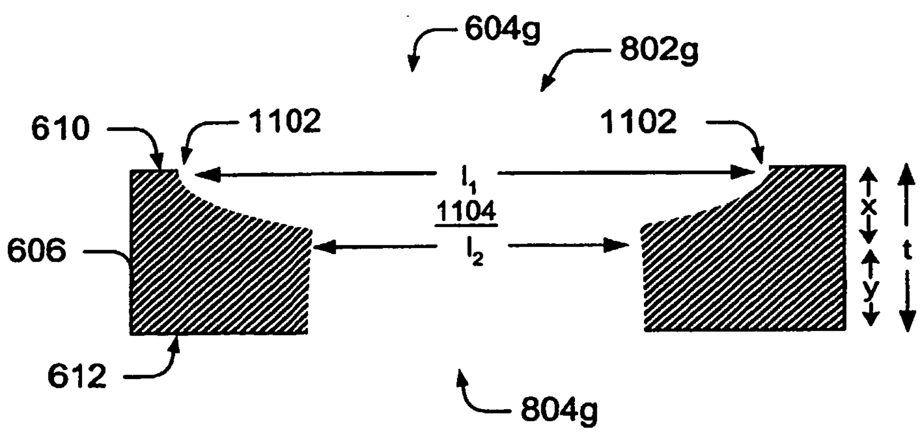


Fig. 11b

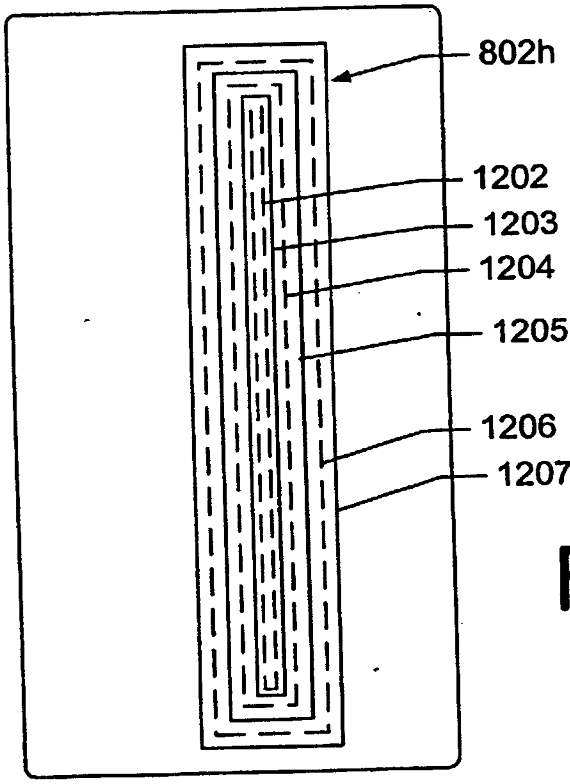
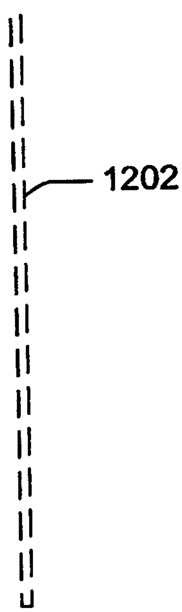
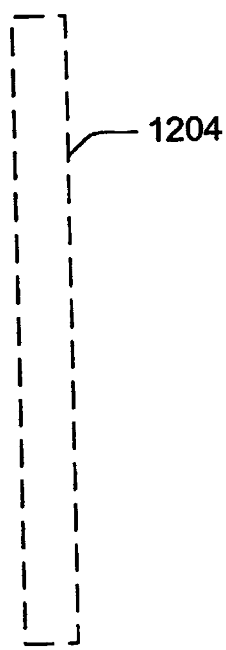


Fig. 12a





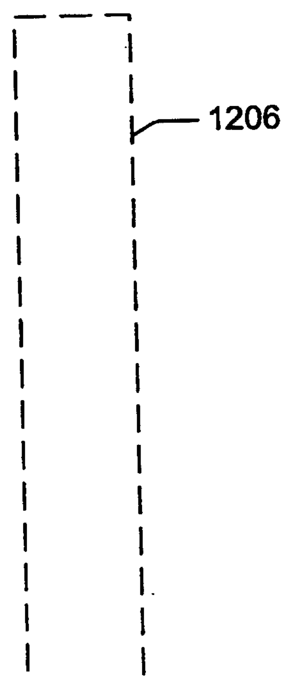


Fig. 12b Fig. 12c Fig. 12d

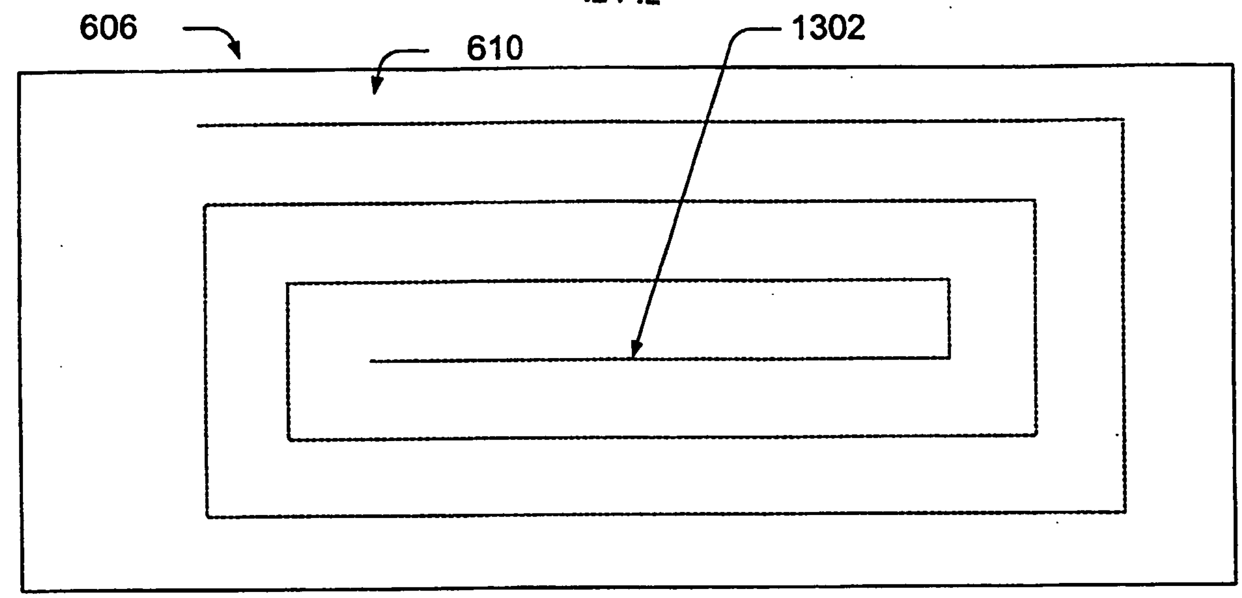


Fig. 13

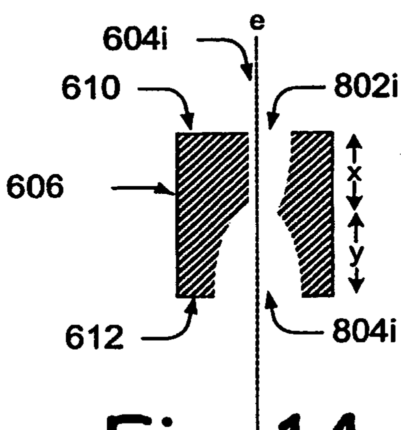


Fig. 14

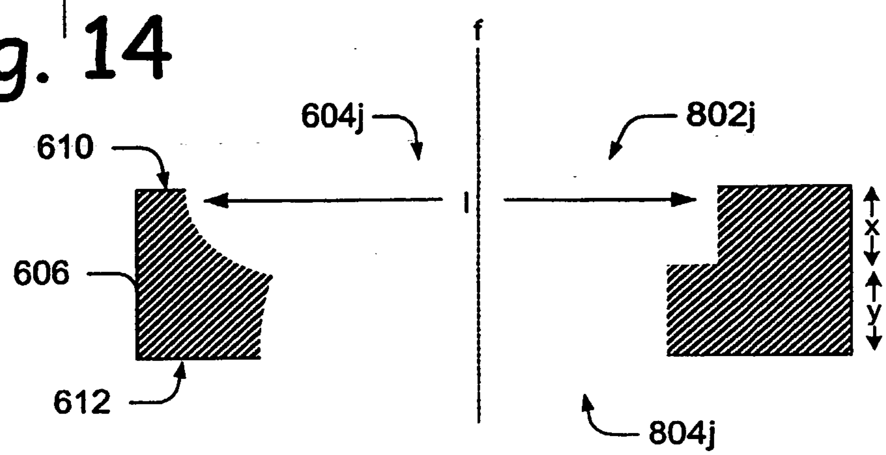


Fig. 15

SLOTTED SUBSTRATES AND METHODS AND SYSTEMS FOR FORMING SAME

BACKGROUND OF THE INVENTION

Inkjet printers have become ubiquitous in society. These printers provide many desirable characteristics at an affordable price. However, the desire for ever more features at ever-lower prices continues to press manufacturers to improve efficiencies. Consumers want ever higher print image resolution, realistic colors, and increased pages or printing per minute. One way of achieving consumer

demands is by improving the print head and its method of manufacture. Currently, the print head is time consuming and costly to make.

Accordingly, the present invention arose out of a desire to provide fast and economical methods for forming print heads and other fluid ejecting devices having desirable characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

The same components are used throughout the drawings to reference like features and components.

Fig. 1 is a front elevational view of an exemplary printer.

Fig. 2 is a block diagram that illustrates various components of an exemplary printer.

Figs. 3 and 4 each show a perspective view of a print carriage in accordance with one exemplary embodiment.

Fig. 5 is a perspective view of a print cartridge in accordance with one exemplary embodiment.

Fig. 6 is a cross-sectional view of a top of a print cartridge in accordance with one exemplary embodiment.

Fig. 7 is a top view of a print head in accordance with one exemplary embodiment.

Fig. 8a-8f and 9a-9h each show a cross-sectional view of a substrate in accordance with one exemplary embodiment.

Fig. 10a is a top view of a print head in accordance with one exemplary embodiment.

Fig. 10b-10d each show a cross-sectional view of a substrate in accordance with one exemplary embodiment.

Fig. 10e is a top view of a print head in accordance with one exemplary embodiment.

Fig. 10f-10h each show a cross-sectional view of a substrate in accordance with one exemplary embodiment.

Fig. 11a-11b each show a cross-sectional view of a substrate in accordance with one exemplary embodiment.

Fig. 12a is a top view of a substrate in accordance with one exemplary embodiment.

Fig. 12b is a top view of an exemplary geometrical pattern in accordance with one exemplary embodiment.

Fig. 12c is a top view of an exemplary geometrical pattern in accordance with one exemplary embodiment.

Fig. 12d is a top view of an exemplary geometrical pattern in accordance with one exemplary embodiment.

Fig. 13 is a top view of a substrate in accordance with one exemplary embodiment.

Fig. 14 is a cross-sectional view of a substrate in accordance with one exemplary embodiment.

Fig. 15 is a cross-sectional view of a substrate in accordance with one exemplary embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

OVERVIEW

The embodiments described below pertain to methods and systems for forming slots in a semiconductor substrate. One embodiment of this process will be described in the context of forming fluid feed slots in a print head die substrate. As commonly used in print head dies, the semiconductor substrate often has microelectronics incorporated within, deposited over, and/or supported by the substrate. The fluid feed slot(s) allow fluid, commonly ink, to be supplied to fluid ejecting elements contained in ejection chambers within the print head. The fluid ejection elements commonly comprise heating elements or firing resistors that heat fluid causing increased pressure in the ejection chamber. A portion of that fluid can be ejected through a firing nozzle with the ejected fluid being replaced by fluid from the fluid feed slot.

The fluid feed slot can be made in various ways. In one embodiment material is removed from the substrate by laser machining a trench through a first substrate surface. A second trench can be formed by various techniques, such as sand drilling, so that the first and second trenches meet to form a slot through the substrate. In some embodiments, the trenches are formed so that they are about equal depth to ensure that they meet at about the middle of the substrate's

thickness. Slots made this way can be very narrow and as long as desired. Narrow slots remove less material and have beneficial strength characteristics that can reduce die fragility. This, in turn, can allow slots to be positioned closer together on the die.

Other embodiments include features that reduce the accumulation of bubbles in the slot. Bubbles can result from the fluid ejection process and can occlude fluid feed if they accumulate in the slot. Various techniques can be utilized to promote bubble migration away from the thin film surface where they are most prone to blocking fluid flow.

Although exemplary embodiments described herein are described in the context of providing dies for use in inkjet printers, it is recognized and understood that the techniques described herein can be applicable to other applications where slots are desired to be formed in a substrate.

The various components described below may not be illustrated accurately as far as their size is concerned. Rather, the included figures are intended as diagrammatic representations to illustrate to the reader various inventive principles that are described herein.

EXEMPLARY PRINTER SYSTEM

Fig. 1 shows one embodiment of a printer 100, embodied in the form of an inkjet printer. The printer 100 can be, but need not be, representative of an inkjet printer series manufactured by the Hewlett-Packard Company under the trademark

"DeskJet" (RTM). The inkjet printer 100 is capable of printing in black-and-white and/or in color. The term "printer" refers to any type of printer or printing device that ejects fluid or other pigmented materials onto a print media. Though an inkjet printer is shown for exemplary purposes, it is noted that aspects of the described embodiments can be implemented in other forms of printing devices that employ inkjet printing elements or other fluid ejecting devices, such as facsimile machines, photocopiers, and the like.

Fig. 2 illustrates various components in one embodiment of printer 100 that can be utilized to implement the inventive techniques described herein. Printer 100 can include one or more processors 102. The processor 102 controls various printer operations, such as media handling and carriage movement for linear positioning of the print head over a print media (e.g., paper, transparency, etc.).

Printer 100 can have an electrically erasable programmable read-only memory (EEPROM) 104, ROM 106 (non-erasable), and/or a random access memory (RAM) 108. Although printer 100 is illustrated having an EEPROM 104 and ROM 106, a particular printer may only include one of the memory components. Additionally, although not shown, a system bus typically connects the various components within the printing device 100.

The printer 100 can also have a firmware component 110 that is implemented as a permanent memory module stored on ROM 106, in one embodiment. The firmware 110 is programmed and tested like software, and is distributed with the printer 100. The firmware 110 can be implemented to

coordinate operations of the hardware within printer 100 and contains programming constructs used to perform such operations.

In this embodiment, processor(s) 102 process various instructions to control the operation of the printer 100 and to communicate with other electronic and computing devices. The memory components, EEPROM 104, ROM 106, and RAM 108, store various information and/or data such as configuration information, fonts, templates, data being printed, and menu structure information. Although not shown in this embodiment, a particular printer can also include a flash memory device in place of or in addition to EEPROM 104 and ROM 106.

Printer 100 can also include a disk drive 112, a network interface 114, and a serial/parallel interface 116 as shown in the embodiment of Fig. 2. Disk drive 112 provides additional storage for data being printed or other information maintained by the printer 100. Although printer 100 is illustrated having both RAM 108 and a disk drive 112, a particular printer may include either RAM 108 or disk drive 112, depending on the storage needs of the printer. For example, an inexpensive printer may include a small amount of RAM 108 and no disk drive 112, thereby reducing the manufacturing cost of the printer.

Network interface 114 provides a connection between printer 100 and a data communication network in the embodiment shown. The network interface 114 allows devices coupled to a common data communication network to send print jobs, menu data, and other information to printer 100 via the network. Similarly, serial/parallel interface 116 provides a data communication path directly between

printer 100 and another electronic or computing device. Although printer 100 is illustrated having a network interface 114 and serial/parallel interface 116, a particular printer may only include one interface component.

Printer 100 can also include a user interface and menu browser 118, and a display panel 120 as shown in the embodiment of Fig. 2. The user interface and menu browser 118 allows a user of the printer 100 to navigate the printer's menu structure. User interface 118 can be indicators or a series of buttons, switches, or other selectable controls that are manipulated by a user of the printer. Display panel 120 is a graphical display that provides information regarding the status of the printer 100 and the current options available to a user through the menu structure.

This embodiment of printer 100 also includes a print engine 124 that includes mechanisms arranged to selectively apply fluid (e.g., liquid ink) to a print media such as paper, plastic, fabric, and the like in accordance with print data corresponding to a print job.

The print engine 124 can comprise a print carriage 140. The print carriage can contain one or more print cartridges 142 that comprise a print head 144 and a print cartridge body 146. Additionally, the print engine can comprise one or more fluid sources 148 for providing fluid to the print cartridges and ultimately to a print media via the print heads.

EXEMPLARY EMBODIMENTS AND METHODS

Figs. 3 and 4 show exemplary print cartridges (142a and 142b) in a print carriage 140. The print carriages depicted are configured to hold four print cartridges although only one print cartridge is shown. Many other exemplary configurations are possible. Fig. 3 shows the print cartridge 142a configured for an up connect to a fluid source 148a, while Fig. 4 shows print cartridge 142b configured to down connect to a fluid source 148b. Other exemplary configurations are possible including but not limited the print cartridge having its own self-contained fluid supply.

Fig. 5 shows an exemplary print cartridge 142. The print cartridge is comprised of the print head 144 and the cartridge body 146. Other exemplary configurations will be recognized by those of skill in the art.

Fig. 6 shows a cross-sectional representation of a portion of the exemplary print cartridge 142 taken along line a-a in Fig. 5. It shows the cartridge body 146 containing fluid 602 for supply to the print head 144. In this embodiment, the print cartridge is configured to supply one color of fluid or ink to the print head. In this embodiment, a number of different fluid feed slots are provided, with three exemplary slots being shown at 604a, 604b, and 604c. Other exemplary embodiments can divide the fluid supply so that each of the three fluid feed slots 604a – 604c receives a separate fluid supply. Other exemplary print heads can utilize less or more slots than the three shown here.

The various fluid feed slots pass through portions of a substrate 606 in this embodiment. Silicon can be a suitable substrate, for this embodiment. In some

embodiments, substrate 606 comprises a crystalline substrate such as single crystalline silicon or polycrystalline silicon. Examples of other suitable substrates include, among others, gallium arsenide, glass, silica, ceramics or a semi conducting material. The substrate can comprise various configurations as will be recognized by one of skill in the art. In this exemplary embodiment, the substrate comprises a base layer, shown here as silicon substrate 608. The silicon substrate has a first surface 610 and a second surface 612. Positioned above the silicon substrate are the independently controllable fluid drop generators that in this embodiment comprise firing resistors 614. In this exemplary embodiment, the resistors are part of a stack of thin film layers on top of the silicon substrate 608. The thin film layers can further comprise a barrier layer 616. The barrier layer can comprise, among other things, a photo-resist polymer substrate. Above the barrier layer is an orifice plate 618 that can comprise, but is not limited to a nickel substrate. The orifice plate has a plurality of nozzles 619 through which fluid heated by the various resistors can be ejected for printing on a print media (not shown). The various layers can be formed, deposited, or attached upon the preceding layers. The configuration given here is but one possible configuration. For example, in an alternative embodiment, the orifice plate and barrier layer are integral.

The exemplary print cartridge shown in Figs. 5 and 6 is upside down from the common orientation during usage. When positioned for use, fluid can flow from the cartridge body 146 into one or more of the slots 604a-604c. From the

slots, the fluid can travel through a fluid feed passageway 620 that leads to a firing chamber 622. A firing chamber can be comprised of a firing resistor, a nozzle, and a given volume of space therein. Other configurations are also possible. When an electrical current is passed through the resistor in a given firing chamber, the fluid can be heated to its boiling point so that it expands to eject a portion of the fluid from the nozzle 619. The ejected fluid can then be replaced by additional fluid from the fluid feed passageway 620.

The embodiment of Fig. 7 shows a view from above the thin-film surface of a substrate incorporated into a print head. The substrate is covered by the orifice plate 618 with underlying structures of the print head indicated in dashed lines in this embodiment. The orifice plate is shown with numerous nozzles 619. Below each nozzle lies the firing chamber 622 that is connected to a fluid feed passageway (feed channel) 620 and then to slot 604a-c. The slots are illustrated in this embodiment as an elliptical configuration when viewed from above the first surface of the substrate. Other exemplary geometries include rectangular among others.

Figs. 8a-8f and 9a-9h show two exemplary embodiments in which portions of the substrate are removed to form one or more slots through the substrate. The illustrated substrate 606 has a thickness t. The described embodiments can work satisfactorily with various thicknesses of substrate. For example, in the specific described embodiments, the thickness can range from less than about 100 microns to at least about 2000 microns. Other exemplary embodiments can be outside of

this range. The thickness of the substrate t in some exemplary embodiments can be about 675 microns.

The slots can comprise a first trench 802 that originates from a first side of the substrate, and a second trench 804 (shown Fig. 8c) that originates from the second side of the substrate. For ease of appreciating these trenches, the figures are shown in corresponding pairs. For example, Fig. 8a is a portion of a cross-section taken along line b-b indicated in Figs. 5 and 7, and shows a length l_1 and depth x of the first trench. Fig. 8b is a portion of a cross section taken along line a-a in Fig. 5. Fig. 8b shows a width w_1 of the trench 802 and the same depth x shown in Fig. 8a of the first trench 802.

In the illustrated embodiments, the length lies along the long axis of the trench and the width lies along the short axis, transverse the long axis. Figs. 8c and 8d and Figs. 8e and 8f have similar relationships showing corresponding cross sections of the length and width.

Referring to Fig. 8a, a first trench 802 is formed by laser machining a portion of the substrate using a suitable laser machining tool 806. In this embodiment, the laser machining tool has a laser source that generates a laser beam 808 that can machine, ablate, or otherwise remove substrate material.

Many satisfactory laser machines can be used as will be recognized by one of skill in the art. In this exemplary embodiment, the laser machine has a laser source that generates a UV laser beam. One suitable laser machine is a UV laser machine called a Xise 200 Laser Machining Tool, manufactured by Xsil of Dublin,

Ireland. In this embodiment, a suitable laser source can use power in the range of about 2 to 100 Watts. In one particular embodiment, the laser source power can be about 4.5 Watts and can have a wavelength of (1060 nm)/n or (1053 nm)/n, where n = 2, 3 or 4. In a specific embodiment, the UV wavelength can be less than about 400 nm, or, in one particular example, about 355 nm. Any suitable pulse width can be employed. In this particular example, the pulse width of the laser beam is about 15 ns, and the repetition rate is about 30 kHz. Additionally, the laser beam can have a diameter of about 5 to 100 microns in this embodiment. In one particular example, the diameter is about 17 microns. Further, the laser machine can have a debris extraction system to remove any debris resulting from the laser machining in this embodiment.

To effectuate substrate removal in a desired pattern, the laser beam passes over the substrate in at least one of several various configurations in this embodiment. For example, the laser beam can be passed over the substrate a single time or multiple times. Additionally, the laser beam can make multiple passes over certain substrate areas and a single pass over other areas. The speed at which the beam is moved over the substrate, as well as the focus of the beam can also be varied to achieve different results depending on the application.

The trench 802 shown in Fig. 8a extends through approximately 50 percent of the thickness of the substrate as indicated by the depth x, and thus has a depth of about 335 microns in this particular example. In other embodiments, the trench can be any depth from less than about 10 microns to a depth that passes through

the entire thickness t. In a most particular embodiment however, the depth x of the trench can be from about 25 percent to about 75 percent of the thickness of the substrate.

Fig. 8c shows a partially completed second trench 804 that is formed from the substrate's second side or surface 612. In various embodiments, the trench can be formed by removing substrate material through the second surface. In this example, sand drilling can be used to form the second trench. Sand drilling is a mechanical cutting process where target material is removed by particles, such as aluminum oxide, delivered from a high pressure air flow system. Sand drilling is also referred to as sand blasting, abrasive sand machining, and sand abrasion.

As an alternative to sand drilling, other exemplary embodiments can use one or more of the following techniques to form the second trench: laser machining, dry etching, wet etching, mechanical machining, and others. Mechanical machining can include the use of various saws and drills that are commonly used to remove substrate material.

Figs. 8e-8f show a finished second trench having a length l_2, a width w_2 and a depth y. The trench intercepts or otherwise joins with a portion of the first trench. The combination of the two trenches forms a slot 604d that extends through the thickness of the substrate and through which a fluid such as fluid can flow. So for at least a portion of the substrate, the depths (x and y) of the two trenches, when taken together, equal the thickness t. As shown in this exemplary embodiment and as best viewed in Fig. 8e, the second trench intercepts the entire

length l_1 of the first trench. Other exemplary embodiments can have less than the entirety of the length of the first trench intercepted by the second trench. An example of such a relationship will be discussed in regard to Figs. 11a-11d. Additionally, as can be appreciated from Fig. 8e, the second trench can be longer than the first trench so that it encompasses a portion of the first trench for its entire length within the second trench.

The exemplary embodiment, shown in Fig. 8f, has a slot 604d formed from a first trench 802 having generally planar side walls and a second trench 804 having generally concave side walls. In this exemplary embodiment, the maximum width w_1 of the first trench is less than the maximum width w_2 of the second trench. Other exemplary embodiments can utilize different configurations.

Although the described embodiments illustrate only removing material from the substrate to form the desired trenches, intermediate steps in some embodiments can actually add material to the substrate. For example, materials might be deposited, through deposition techniques, as part of the slot formation sequence and then be either partially or completely removed.

Alternatively, some exemplary embodiments can utilize one or more additional procedures beyond those described above and below to clean or otherwise improve a slot. For example, in one exemplary embodiment, a first trench can be made by dry etching from one side and a second trench can be laser machined from the other side until it intercepts the first trench to form a slot. Another additional procedure, such as sand drilling, can be utilized to clean up or

remove any debris left from the slot formation process in this exemplary embodiment. The clean up procedure can be performed once the slot is formed as described in this example, or alternatively, can be done after some material has been removed, but before the slot is completely formed.

The dimensions of the trenches can be modified to make a through slot of any desired length and/or width. For example, the length of the slot can be made short enough so that it resembles a hole or via.

The process of forming a portion of the slot from each side of the substrate can provide many desirable advantages. One advantage pertains to the dimensions of the slot width. For example, a greatly reduced slot width can be formed using the techniques described above, as compared with the width of a slot that is formed entirely from a single side.

For example, on a standard 675 micron thick substrate, a first trench of about 80 microns in width can be laser machined through about one-half of the thickness of the substrate from a first side. The remainder of the thickness of the substrate can be removed from the second side by sand drilling.

In an exemplary embodiment where the first side comprises the thin film side, the maximum width of the slot can be located on a portion of the backside trench near or at the backside surface and can be about 300 microns. In one exemplary embodiment, the maximum width of the backside trench is about 240 microns where the front side width is about 80 microns. This allows a maximum trench width of about 300 percent of the width of the thin-film side of the slot.

Viewed another way, the maximum width of the through slot is about 50 percent or less of the thickness of the substrate. In this exemplary embodiment, the aspect ratio is about 2.8, where the aspect ratio equals the substrate thickness divided by the slot width. The described techniques allow much higher aspect ratios to be achieved as desired.

Conversely, forming a slot using sand drilling alone can form a slot with a width of about 180 microns on the thin film side and a backside width of about 650 microns for a substrate of about 670 microns thickness. Thus, the maximum slot width is approximately equal to the substrate thickness, so the aspect ratio is approximately 1. A slot, sand drilled from a single surface, often removes a large amount of substrate material making the remaining substrate more fragile. Further, the wide backside trench leads to an undesirably large distance between adjacent slots on a multi-slot substrate or die.

Forming a significant portion of the slot from each side not only allows a narrower slot width than sand drilling alone, but can also form a slot of much better quality. For example, a slot that is sand drilled entirely from the backside creates stresses on the underside of the thin film layer on the front side of the substrate before "breakthrough" occurs. Breakthrough is the moment when the entire thickness of a given portion of the substrate has been removed. When breakthrough occurs at the thin film side, large stress forces can often weaken the substrate and associated microelectronics, and often can, when completed by sand drilling, cause large chips of at least about 45-50 microns to be broken from the

sides of the slot. This chipping often hinders the print quality of the die.

In one particular embodiment, when laser machining is conducted first from the first side through about one half of the substrate, breakthrough from the second side occurs generally in the middle of the substrate. Consequently, chipping is both reduced at this mid location, and less critical than when on the thin film side/surface. Further, in this embodiment, the substrate is less susceptible to stress induced breakage when the breakthrough occurs toward the center of the substrate's thickness. Also, in this embodiment, laser machining can create trenches with much less variation than sand drilling. In one embodiment, laser machining can cut a trench within about 7 microns of a desired location and can have less than about 4 microns of variance along a given laser cut trench. This small variance can be especially valuable on the thin-film portion where such a precisely formed trench can be advantageous to printer function. The laser also allows increased variation in trench shape. Both of these properties can be advantageous and will be discussed in more detail below.

The laser cutting process is very precise, but its efficiency can diminish when making deep cuts, such as cutting all the way through a substrate from one side. By laser cutting a portion of the trench from one side in combination with removing material from the other side, the advantages can be increased and the disadvantages reduced.

Figs. 9a-9h show an exemplary embodiment, where the laser is used to make a stair stepped or graduated trench from one side after a first trench is made

from the other side.

In Figs. 9a and 9b substrate material has been removed to form a trench 802a through the second surface 612. In this embodiment, sand drilling was utilized, though as described above, other techniques can form a satisfactory trench.

In this embodiment, Figs. 9c-9d show a partially formed second trench 804a formed by laser machining from the first side 610. The second trench 804a has length l_1 and width w_1.

In the embodiment of Figs. 9e-9f, the laser beam has removed additional material from the first surface of the substrate. In this embodiment, this second laser removal step has increased the depth x of the trench 804a. In this embodiment, the newly removed portion has a length l_2 and width w_2 each of which are less than l_1 and w_1 of Figs. 9c-9d. These changes in trench dimensions can be achieved by, among other things, changing the pattern or footprint that the laser beam traces on the substrate. Various other configurations will be discussed in more detail below.

Figs. 9g-9h show the results where the laser beam has removed additional substrate material from the thin film side to form a finished trench 804a and a slot 604e. This technique has created a stair step configuration or pattern as can be seen in the alternating vertical and horizontal surfaces comprising the laser machined trench in these Figs.

Though only three distinct stair steps are shown, other exemplary

embodiments can have any number of steps or graduations. In some exemplary embodiments, the number of graduation can be such that individual steps become almost imperceptible.

Figs. 10a-10e show another exemplary embodiment utilizing a stair-step or graduated laser machined trench in a substrate having microelectronics incorporated upon it.

Fig. 10a shows a view from above the thin film side of a substrate having microelectronics 1001 incorporated thereon, in one embodiment. A laser beam has made a first cut 1002 through the thin film surface 610 of the substrate to partially form a trench 802f in this embodiment. This first cut has damaged substrate material in proximity to the cut in this embodiment. This damaged or "heat affected zone" 1004 can be caused by heat and other energy from the laser beam that damages surrounding substrate material and/or microelectronics. Thus, it can be advantageous to limit the heat affected zone especially where any portion of the microelectronics is within it.

The embodiment of Fig. 10b shows a cross-section taken along line c-c of the substrate shown in Fig. 10a, and shows the relatively deep but narrow first cut 1002. As illustrated in this embodiment, the trench is generally rectangular, and in this particular embodiment, the sidewalls of the trench are generally orthogonal to the first surface 610. Fig. 10c is an embodiment that shows the results of a second cut 1006 that removed additional material, in a process after the formation of the substrate shown in Fig. 10b. It will be noticed that this second cut increased the

footprint of the partially formed trench but not the depth. In this embodiment, the trench has alternating generally horizontal and generally vertical surfaces that can create a stepped configuration. This configuration can be seen from a plan view in Fig. 10e at a subsequent step in the process of the current embodiment as will be discussed in more detail below.

Fig. 10d shows a further cross-sectional view of this embodiment taken along line d-d in Fig. 10e. Fig. 10d shows the results of a third laser cut 1008. In this embodiment, this cut further increases the footprint of the trench 802f without increasing the depth. This embodiment further contributes to the stepped configuration by adding an additional step from the previous embodiment shown in Fig. 10c.

The embodiment of Fig. 10e returns to the top side view of Fig. 10a with the addition of the second and third cuts. It can be seen in the embodiments shown in Figs. 10d and 10e that much of the heat-affected zone made by the first laser cut has been removed by the subsequent cuts.

In this embodiment, the heat affected zone caused by the first deep narrow trench did not extend into the nearby microelectronics 1001 and much of it was removed in the subsequent steps. In one embodiment, the subsequent cuts remove most of the damaged material without creating a significant additional heat affected zone, because any heat generated can dissipate into the first cut and the ambient air rather than the adjacent substrate, among other reasons.

Other exemplary embodiments can remove damaged substrate material 1004 by sand drilling a second trench from the backside that intercepts the first trench associated with the damaged substrate material. This can be done alone, or in combination with the technique described above with respect to the embodiments shown in Figs. 10c-10d. For example, Fig. 10f shows an embodiment of the substrate depicted in Fig. 10d with a second trench 804f partially formed from the second surface 612. Fig. 10g shows one embodiment of the same substrate right after breakthrough has occurred at approximately the middle of the substrate's thickness. Fig. 10g is an embodiment where the second trench 804f has generally concave walls while the first trench 804f has a stair step configuration.

Fig. 10h shows an embodiment having further substrate material removed by the sand drilling process. In this exemplary embodiment, sand drilling was used to remove damaged substrate material and clean up the slot 604f. This embodiment can be advantageous since breakthrough occurred away from the microelectronics and thin film surface. In addition to removing damaged substrate material, the sand drilling of this embodiment was used to further configure the slot 604f. In this exemplary embodiment, the sand drilling process was continued after breakthrough to achieve a smoother more uniform slot. The sand drilling process can also be utilized to control the final width of the slot in another embodiment. The described embodiments can provide a slot that has an aspect ratio that is favorable relative to a slot formed by sand drilling alone. In one

embodiment, this favorable aspect ratio can provide a stronger substrate and can minimize the total processing time of slot formation and thus minimize cost.

The embodiment of Fig. 10h can additionally be beneficial in preventing the accumulation of bubbles in the slot. The formation of bubbles can result from the fluid ejection process. An accumulation of bubbles can occlude fluid from reaching the firing chambers and hence cause printer malfunction. It can be beneficial that bubbles not remain in proximity to the inlets of the fluid feed passageways or any other region of the fluid feed slot where they could hinder or occlude fluid supply to the firing chambers.

In some embodiments, bubble accumulation has hindered previous attempts to make a front side trench that was substantially longer or wider than the backside trench that supplied it. The previously described embodiments can allow the backside trench to be shorter than the front side trench without having gas bubbles accumulate in the slot. Specifically, recall that, as shown in the embodiments Figs. 9a-9h, the substrate is effectively upside down from the configuration in which it is commonly used. In this embodiment, the stair step configuration can eliminate areas where bubbles would otherwise tend to accumulate. Specifically, in this embodiment by having multiple narrow shelves, bubbles that tend to form during the fluid ejection process tend to migrate or disperse into the backside trench away from the thin film side.

The stair step configuration can be utilized on both the width and the length as shown in the embodiment of Fig. 10e. Alternatively, a stair step configuration

can be used on only the length or the width. For example, a common width can be maintained for multiple laser cuts that form the first trench while the lengths are made progressively shorter or longer as desired.

The stair step or graduated configuration of the embodiment shown in Figs. 10g and 10h are two of the possible configurations that can reduce the amount of silicon removed from the substrate thus increasing die strength and decreasing manufacturing cost and time.

In some embodiments, other configurations can also reduce bubble accumulation. These embodiments include, in addition to the stair step configuration, contoured and tapered configurations, among others. For example, Figs. 11a-11b show an exemplary embodiment where a laser beam formed a contoured trench that can reduce bubble accumulation in the slot.

Referring now to Fig. 11a, a laser beam has formed a first contoured trench 802g of length l_1 in the thin film side 610 of the substrate 606 in this embodiment. This trench is shallowest toward its peripheral edges or region 1102 that define the borders of the trench at the thin film surface and is deeper in a central region 1104.

Fig. 11b shows an embodiment of substrate 606 that has a second trench 804g formed from the backside and intercepting portions of the first trench to form a slot through substrate 606. In this embodiment, the backside trench 804g intercepts the central region 1104 of the first trench 802g. In this exemplary embodiment, the first trench 802g has a maximum length l_1 that is near the first surface 610. The second trench 804g also has a length l_2 where it intercepts the

first trench 802g in this embodiment.

When the first trench is formed on the thin film side, the contoured configuration of this embodiment can allow the backside trench to be much shorter than the thin film trench while still providing adequate fluid flow and minimizing bubble accumulation. In an exemplary embodiment, the length of the laser machined trench l_1 can be at least about 200 percent the length l_2 of second trench 804g.

In one embodiment, a front side trench that is significantly longer than the backside trench can allow the backside trench to be formed faster since the amount of substrate material that is removed in the longitudinal direction in forming the slot can be reduced. Additionally, since less substrate is removed, the remaining substrate of this embodiment is structurally stronger and less likely to break when incorporated into an end use product such as a print cartridge. Also, since the substrate is stronger in this configuration, the slots can be placed closer together on the substrate thus allowing for decreased material costs.

In some exemplary embodiments, the thin film trench can have a minimum depth at the peripheral edges 1102 to ensure adequate fluid flow to the various fluid feed passageways 620 and ejection chambers 622 (Fig. 7) supplied by the slot. In some exemplary embodiments, this minimum depth can be about 10 microns.

In other exemplary embodiments, the peripheral region of the thin film trench can also be configured to allow the various fluid feed passageways to be of

uniform length and/or geometry from the slot to the individual firing chamber 622 (which are often staggered from each other) they supply. For example, a shelf portion of the thin film trench can be formed that provides this uniform configuration. Because laser machining is so precise, additional embodiments can provide fluid feed passageways, that though of differing lengths, are of precisely known lengths. These features can allow increased print head performance.

The contoured shape of trench 802g illustrated in the embodiments Figs. 11a-11b can be achieved with many satisfactory techniques. For example, the focus of the laser beam can be adjusted so that the part of the beam striking a more central area of the slot receives greater energy than the portion striking more peripheral areas. Additionally, or alternatively, the speed at which the laser beam is passed over the substrate can be adjusted as desired. For example, the laser beam can be slowed over the central areas of substrate and sped up over the peripheral areas to create varying depths as desired.

Satisfactory embodiments of laser trenches can be made in many ways. For example, Figs 12a-d show an exemplary embodiment in which a stair stepped configuration is achieved by tracing the laser beam over the substrate in a multiple cookie cutter pattern. The embodiment shown in Fig. 12a is a view from above the first surface of a substrate, similar to Fig. 10e. The trench 802h depicted in the embodiment of Fig. 12a is basically a trench 1203 within a trench 1205 within a trench 1207. In one embodiment, this configuration can be achieved by passing the laser beam over the substrate following the multiple cookie cutter shapes or

patterns (shown as dotted lines) 1202, 1204, and 1206. The corresponding cookie cutter shapes are shown individually in Figs. 12b-12d.

The cookie cutter shapes shown in this embodiment are rectangular, but many other shapes including elliptical shapes can also be used. The speed of movement, intensity, and focus of the laser beam can be held constant or adjusted as desired to achieve a given configuration in alternative embodiments.

Other patterns can also be used for achieving a desired trench configuration. For example, Fig. 13 shows an exemplary laser path as dotted line 1302 on the first side 610 of the substrate 606. The laser path in this embodiment is an expanding pattern that can remove substrate in a rectangular configuration to form a first trench. Those of skill in the art will recognize other satisfactory embodiments.

The illustrated embodiments have been generally symmetrical; however, such need not be the case. For example, Fig. 14 is a cross-sectional view taken transverse the long axis of a trench similar to the view shown in Fig. 8f. This exemplary embodiment shows a cross-section of a width of a slot 604i that is defined by a first trench 802i and a second trench 804i. In this exemplary embodiment, the first trench is asymmetrical in the sense that relative to or about a plane into and out of the page that is orthogonal to the first surface 610 and that bisects the cross-section of the trench, the portion of the trench on the left side of the plane does not match that on the right. The described plane passes through dashed line e that is shown in Fig. 14 as a reference. It can be seen from the drawing that substantially more of trench 802i is on the right side of line e through

which the reference plane passes than is on the left side. In this embodiment, a portion of the slot 604i on the left of line e is generally planar and orthogonal to the first surface, whereas a portion of the slot on the right of the line e is generally contoured.

Similarly, the embodiment of Fig. 15 shows a cross-sectional view along the long axis of the slot 604j. In this exemplary embodiment, the first trench 802j is asymmetrical in the sense that relative to or about a plane into and out of the page that is orthogonal to the first surface 610 and that bisects the cross-section of the trench, the portion of the trench on the left side of the plane does not match that on the right. Dashed line f is provided as a point of reference through which the described plane passes. In this embodiment, a portion of the slot 604j on the left of line f has a contoured configuration whereas a portion of the slot 604j on the right is generally planar and generally orthogonal to the first surface 610. Other satisfactory embodiments can comprise a combination of various areas of symmetry and asymmetry as well as offsetting the first and second trenches in relation to one another.

CONCLUSION

The described embodiments can provide methods and systems for forming slots in a substrate. The slots can be formed by laser machining from a first surface and removing material through the use of various techniques from a second surface. The slots can be inexpensive and quick to form and have aspect ratios

higher than existing technologies. They can be made as long as desirable and have beneficial strength characteristics that can reduce die fragility and allow slots to be positioned closer together on the die.

Although the invention has been described in language specific to structural features and methodological steps, it is to be understood that the invention defined in the appended claims is not necessarily limited to the specific features or steps described. Rather, the specific features and steps are disclosed as preferred forms of implementing the claimed invention.

CLAIMS

1. A method of forming slots (604) in a substrate (606) having opposing first (610) and second (612) surfaces comprising:

making a laser cut through either the first or second surface of the substrate (606) sufficient to form a first trench (802); and,

removing material (804) through the other of the first and second surfaces of the substrate (606) effective to form, in combination with said laser cut, a slot (604) at least a portion of which passes entirely through the substrate (606), and wherein said slot (604) has an aspect ratio greater than or equal to 1.

2. The method of claim 1, wherein said removing (804) comprises one or more of: laser machining, sand drilling, dry etching, and wet etching.

3. The method of claim 1, wherein said making a laser cut forms a first trench (802) having a shape that facilitates bubble dispersal during fluid ejection.

4. A fluid ejection device (142) having a substrate (606) formed in accordance with the method of claim 1.

5. A method of forming fluid handling slots (604) in a semiconductor substrate (606) having a thickness defined by a thin film side (610) and a backside (612) comprising:

laser machining into the semiconductor substrate (606) from the thin film

side (610) to form a first trench (802); and,

removing semiconductor substrate (606) material from the backside (612) to form a second trench (804), wherein at least a portion of the first (802) and second (804) trenches intersect to form a slot (604) through the semiconductor substrate (606).

6. The method of claim 4, wherein said laser machining forms a first trench (802) at least portions (1102) of which are configured to allow bubbles to migrate away from the thin film side (610).

7. The method of claim 4, wherein said laser machining forms a first trench that is asymmetrical (802i).

8. A method of forming a fluid handling slot (604) in a semiconductor substrate (606) having a thickness between first (610) and second (612) opposing surfaces and microelectronics integrated thereon, comprising:

creating, with a laser machining process, a first trench (802) in the semiconductor substrate (606) within one of the first and second surfaces; and,

forming a second trench (804) in the semiconductor substrate (606) within the other of the first and second surfaces, wherein at least portions of the first and second trenches join together to form a slot (604), wherein the maximum width of the slot is about 50 percent or less of the thickness of the substrate (606).

9. The method of claim 8, wherein creating a first trench (802) comprises creating a first trench (802) that passes through about 25 percent to about 75 percent of the thickness of the substrate (606).

10. The method of claim 8, wherein the act of forming a second trench (804) occurs after the act of creating the first trench (802).

The Patent Office

PATENTS • DESIGNS • COPYRIGHT • TRADE MARKS

33

CHARTER MARK

INVESTOR IN PEOPLE

Application No: GB 0301948.6 **Examiner:** Marc Collins
Claims searched: 1-10 **Date of search:** 10 March 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	1-2, 4-5, 8-9	US 5455998	(MIYAZONO et al.) See whole document especially figure 15 and claims 1, 2 and 4.
A	-	EP 0764533 A2	(LEXMARK INTERNATIONAL INC.) See whole document.
A	-	EP 0609012 A2	(HEWLETT-PACKARD CO.) See whole document.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{V}:

B6F

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

B41J

The following online and other databases have been used in the preparation of this search report:

EPODOC, JAPIO, WPI